International Test Facilities

Snowmass 2021 Community Planning Meeting
Session 175: Accelerator research centers and test facilities for future accelerators

Virtual

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Ralph W. Aßmann, DESY

HELMHOLTZ
RESEARCH FOR GRAND CHALLENGES

MATTER AND TECHNOLOGIES

Introduction

Scope of this talk

From Tor Raubenheimer:

One of the key goals of the Snowmass'21 Accelerator Frontier is to address the question "What are the **time and cost scales of the R&D and associated test facilities** as well as the time and cost scale of the facility?"

- There are a large number of accelerator test facilities and R&D efforts in the other regions, mainly in Europe and Asia.
- Problem: No chance to even list all acronyms and explain them in the **10 minutes** of this talk.
- Please take this talk as a **short glimpse at some of the international test facilities** that exist, are discussed or being implemented…
- Focus here on **technologies with strong R&D needs** to prove basic feasibility for a collider: test and demonstration facilities are of key importance for advancing towards a linear collider! Several collider studies (ILC, FCC, ERL-based, ...) and associated test facilities perform outstanding R&D, but are more advanced and not covered here for time reasons. Also: **Focus on LOI submissions** to the Snowmass'21 process.
    - **Muon collider** test facility (input from Nadia Pastrone, Daniel Schulte, Mark Palmer).
    - **Plasma / dielectric accelerator** test facilities

Muon Collider R&D

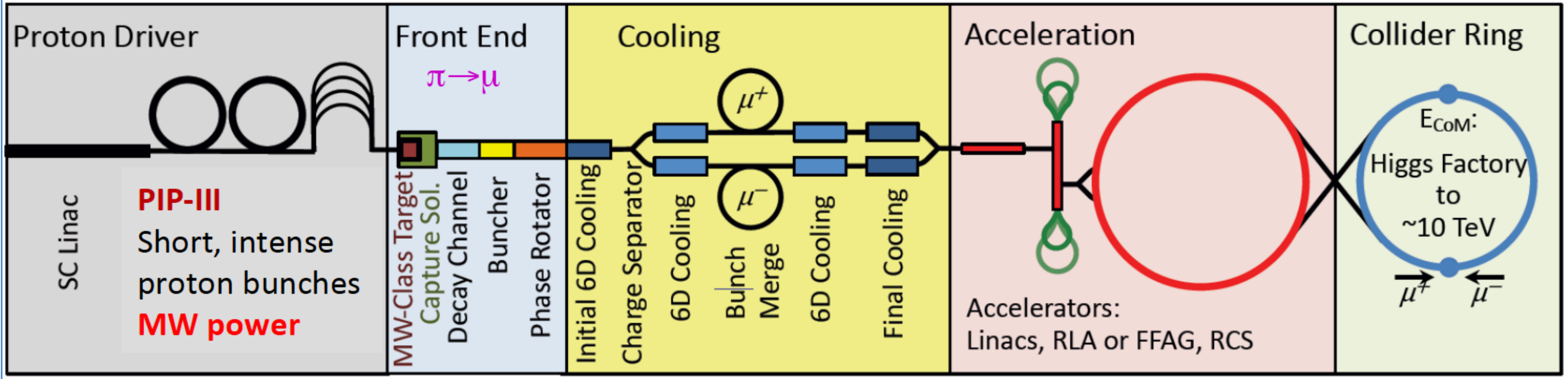
(material and input from Nadia Pastrone, Daniel Schulte, Mark Palmer)

- The recent update of the European strategy has pointed out muon colliders as subject of interest and R&D for the future of particle physics.
- This will likely result in the future proposal and implementation of an **international test or demonstrator facility for muon collider R&D**, too early to be defined now in detail.
- A working group has been formed to scientifically justify the investment into a demonstration programme before the next strategy process and to define what this programme should contain.
- The core test facility might be a cooling facility. There will certainly be prototype development and most likely beam tests.
- Full tests for both the proton and the positron-based sources for a muon collider might be excluded due to limited resources.
- Beam tests will be relevant since for example the LEMMA design currently uses collision beta-functions of 0.2 mm in both planes, which I only saw in the plasma collider proposals.

Muon Colliders: MAP Scenario

Input:
π, μ produced from Proton Bunch ~10^{14}, 1 m long
~0—1 GeV/c, $\varepsilon_{t,N}$ ~ 0.02 m

Output:
Cooled μ^+ and μ^- bunch ~10^{12} / bunch
$\varepsilon_{t,N}$ ~ 0.00002 m,



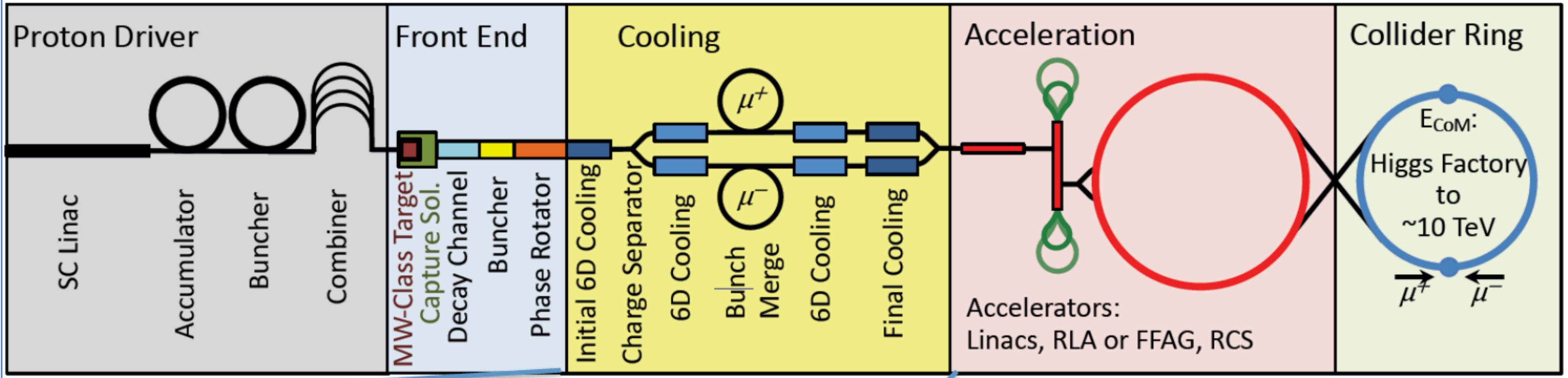
Target
Produce pions

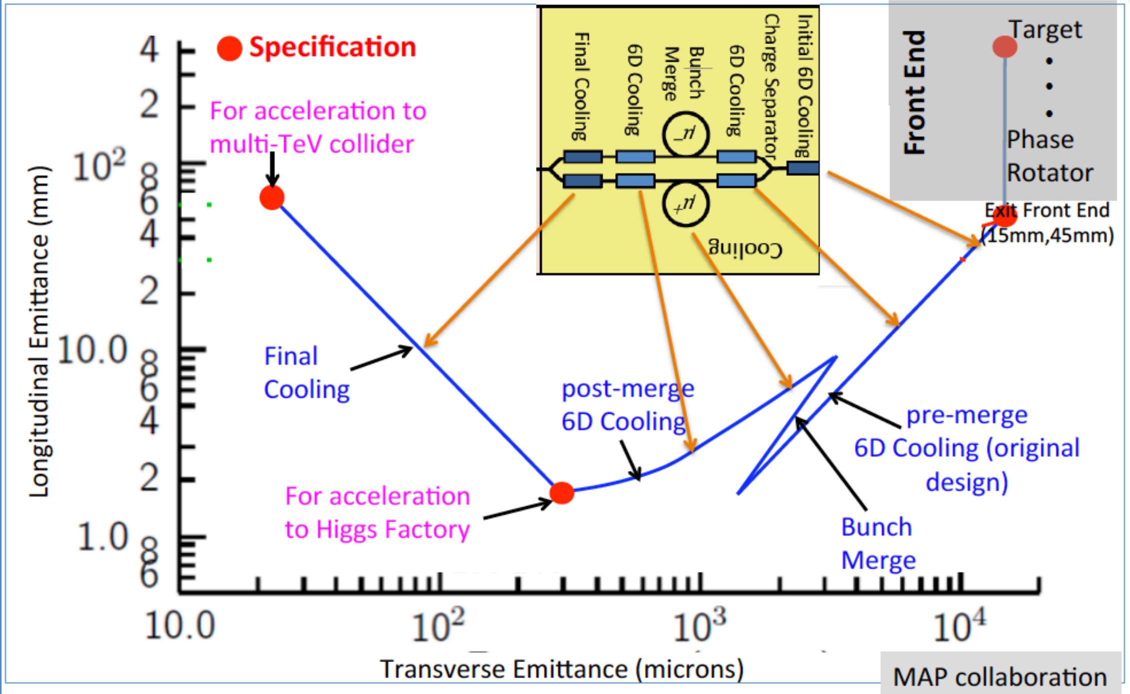
Capture
Collect and cool muons from pion decay

Cooling
Single pass →
Ring coolers,
Improve final cooling
PIC cooling ??

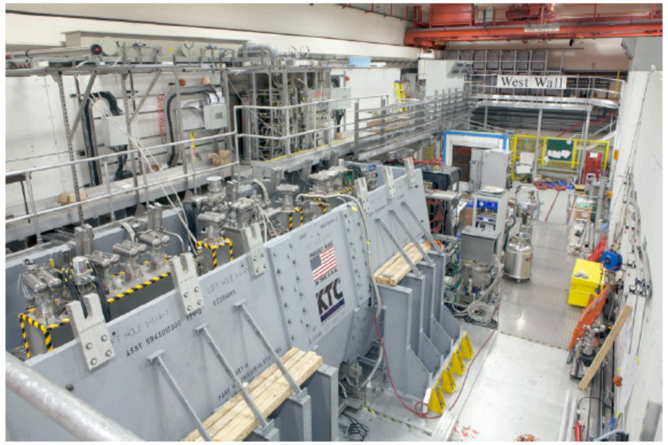
Collider rings for
0.125, 1.5, 3, 6 TeV designed

Muon Collider (Proton-driven)





First demonstration in MICE (UK)
But need new facility with RF and stages and significantly more cooling



Plasma / Dielectric Accelerator Test Facilities

International landscape of test facilities highly populated

High gradient, ultra-compact new acceleration technologies often **originate in universities or smaller groups**. Technology and setup is comparably inexpensive and easily accessible.

- There exist **more than 30 experiments, setups and facilities in Europe and Asia**, mainly for plasma acceleration but also a handful for dielectric accelerators.
- The field is only recently moving to the large accelerator labs in Europe and Asia. Smaller facilities live on and continue producing outstanding accelerator science and innovative solutions.

Here: Focus on efforts with international scope and ambition. Also: Focus on topics and facilities with **LOI submissions** to the Snowmass’21 process.

- Apologies to efforts in Japan (Osaka – RIKEN, SPring-8) who are building up an important Japanese facility on the site of RIKEN-SPring-8.
- Apologies to highly successful facility in Korea and impressive facility plans in China.
- Apologies to the many local or national facilities in Europe not mentioned.

As said before: just a short glimpse to international facilities…

ALEGRO

Towards an Advanced Linear International Collider

- See LOI by Brigitte Cros and Patric Muggli and AF6 presentation by B. Cros.
- ALEGRO LOI provides a list of test facilities and highlight goals.

ALEGRO LOI for Snowmass2021

Towards an Advanced Linear International Collider

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Endorsed by the Advanced and Novel Accelerator panel of ICFA https://icfa.fnal.gov/

Authors: B. Cros[1], E. Gschwendtner (CERN), S. Hooker (JAI, U. Oxford), P. Muggli[2], J. Osterhoff (DESY), M. Peskin (SLAC), P. Piot (NIU, ANL), J. Power (ANL), C. Schroeder (LBNL), J.-L. Vay (LBNL), J. Viera (IST)

On behalf of ALEGRO collaboration
member list at http://www.lpgp.u-psud.fr/icfaana/alegro/alegro-members

B. Cros et al

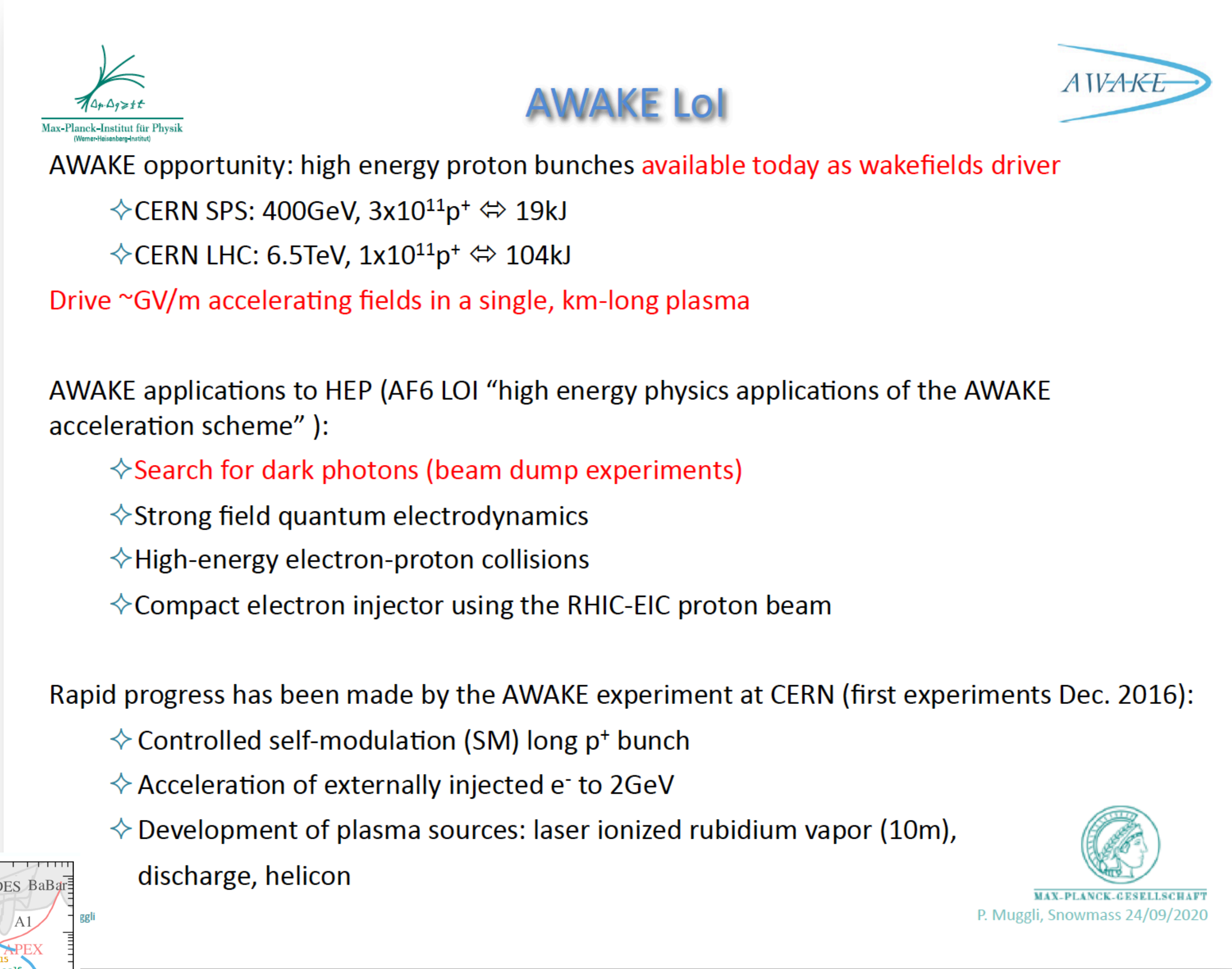
Facility	Readiness	ANA	Specific Goals ★ Based in EU
BELLA	Operating	LWFA	**e⁻, 10 GeV, multi-GeV staging**
kBELLA	Design study	LWFA	**e⁻, 1 GeV, kHz rep rate, 1 kW avg. power**
KALDERA ★	Start 2025	LWFA	**e⁻, 1 GeV, kHz rep rate, 1 kW avg. power**
EuPRAXIA ★	Design study	LWFA, PWFA	**e⁻, 5 GeV, reliability**
AWAKE ★	Operating	PWFA p-driven	**e⁻, beam quality, multi-GeV, HEP fixed target exp.**
FACET II	Start 2020	PWFA	**e⁻, 10 GeV boost, beam quality, e⁺ acceleration**
FLASHForward ★	Operating	PWFA	**e⁻, 1.5 GeV, beam quality, high rep rate, 10 kW avg. power**
AWA	**Operating**	**SWFA**	**e⁻, sub-GeV, high charge, beam shaping, TBA and CWA**

DESY intensifies efforts towards high average power

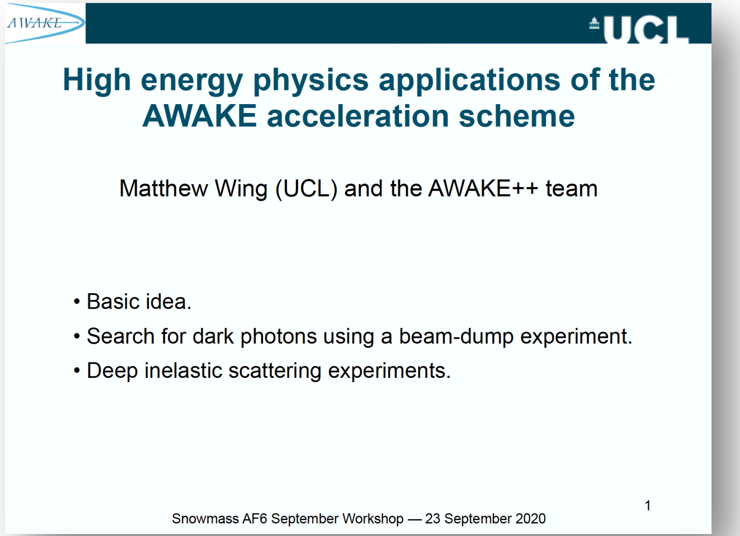
AWAKE

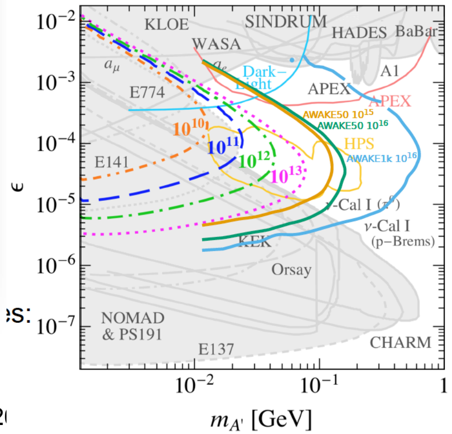
Proton-driven plasma acceleration based at CERN

- See LOI's by AWAKE and AF6 presentation by M. Wing and P. Muggli.
- Test facility can also serve pre-collider goals, e.g. search for dark photons and deep inelastic scattering experiments.



P. Muggli



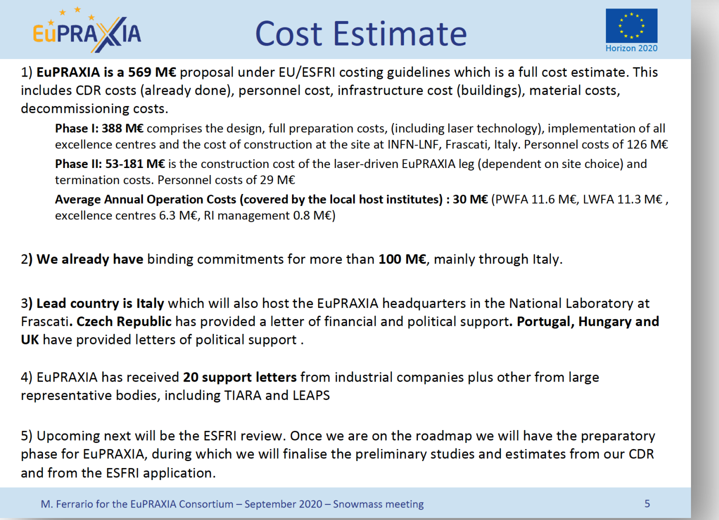


M. Wing

EuPRAXIA

European plasma accelerator with FEL + other applications

- See LOI by EuPRAXIA, AF6 presentation by M. Ferrario.
- Test/demonstration facility can also serve pre-collider goals, e.g. FEL for high beam quality, e+, multi-stage.
- Start of pilot user operation planned for 2028:
  - EU-funded CDR (incl. resource estimates, planning) started in 2015, has been completed and published.
  - Bringing together facilities at 48 members and observers institutes in 15 countries.
  - Aiming at 2 construction sites. Frascati/Italy started.
  - 569 M€ project (full cost) with >100 M€ already approved.
- Project submitted to 2021 ESFRI Roadmap Update at EU (European Strategy Forum for Research Infrastructures). Formal government support: Italy, Czech, Portugal, Hungary, UK



EuPRAXIA — **Cost Estimate** — Horizon 2020

1) **EuPRAXIA is a 569 M€** proposal under EU/ESFRI costing guidelines which is a full cost estimate. This includes CDR costs (already done), personnel cost, infrastructure cost (buildings), material costs, decommissioning costs.

Phase I: 388 M€ comprises the design, full preparation costs, (including laser technology), implementation of all excellence centres and the cost of construction at the site at INFN-LNF, Frascati, Italy. Personnel costs of 126 M€

Phase II: 53-181 M€ is the construction cost of the laser-driven EuPRAXIA leg (dependent on site choice) and termination costs. Personnel costs of 29 M€

Average Annual Operation Costs (covered by the local host institutes) : 30 M€ (PWFA 11.6 M€, LWFA 11.3 M€ , excellence centres 6.3 M€, RI management 0.8 M€)

2) **We already have** binding commitments for more than **100 M€**, mainly through Italy.

3) **Lead country is Italy** which will also host the EuPRAXIA headquarters in the National Laboratory at Frascati**. Czech Republic** has provided a letter of financial and political support**. Portugal, Hungary and UK** have provided letters of political support .

4) EuPRAXIA has received **20 support letters** from industrial companies plus other from large representative bodies, including TIARA and LEAPS

5) Upcoming next will be the ESFRI review. Once we are on the roadmap we will have the preparatory phase for EuPRAXIA, during which we will finalise the preliminary studies and estimates from our CDR and from the ESFRI application.

M. Ferrario for the EuPRAXIA Consortium – September 2020 – Snowmass meeting 5

Dielectric Laser Accelerators

ACHIP International Collaboration

- See LOI by and AF6 presentation by Joel England et al.
- This is an international collaboration, relating to several test facilities in- and outside of the US.
- European facilities involve SwissFEL at PSI (Switzerland), Erlangen and ARES/SINBAD at DESY (Germany).
- Good example of international coordination and synergy.

Gradient and Energy Scalability:

• High-gradient operation with **850 MeV/m** average electron gradient and **0.3 MeV** energy gain and **phase/dispersion control**. Higher gradients possible -- 1.8 GV/m axial fields experimentally demonstrated in fused silica DLA. (UCLA, D. Cesar 2018)

• POCs have demonstrated key concepts needed for energy scaling: transverse and longitudinal **focusing**, optical **pre-bunching** and injection, **net acceleration**, integrated waveguide **coupling,** extended transport**, staging** of laser pulses**.**

• **ACHIP aims to develop a cm-scale 1 MeV tabletop accelerator by FY21**

Dielectric Laser Accelerators

Snowmass AF6 Meeting Sept 23, 2020

R. J. England

Current and Future Test Facilities

SLAC

Current Test Facilities:

UCLA Pegasus: 1-8 MeV photoinjector+linac; Ti:Sapphire laser; low-charge, norm. emittance ~ 30nm-rad
High gradient and high energy gain demonstration experiments

Stanford: 30 to 100 keV nanotip emission sources for low-energy structure evaluation

FAU Erlangen: 30 kV SEM and supertip field emission source test stands; 2μm laser testing

Future Planned (Funded) Test Facilities (1 to 5 year timeline):

PSI SwissFEL 3 GeV beam line - dedicated DLA diagnostic and vacuum chamber
Laser driven undulator, wakefield studies, radiation damage testing

DESY SINBAD 100 MeV beamline -- short bunches (few fs); optically microbunched beams anticipated
Net acceleration experiments; particle deflection/streaking

FAU and Stanford: 1 MeV university test bench: demonstrate basic staging and integrated component capabilities; proposed outcome of ACHIP

Other Potential Test Facilities (1 to 5 year timeline):

NLCTA (SLAC) – currently in minimal operation mode; used in earlier (2013-2015) experiments

ATF (BNL) – high power CO_2 laser; capabilities for hosting advanced accelerator experiments

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Other Test Facilities on Specific Topics *(not in short ALEGRO list)*

Advancing spin polarization and hybrid plasma accelerators

- e+e- colliders and physics reach enhanced by spin polarized beams
- See LOI and AF6 presentation by M. Büscher and A. Lehrach
- International Partners: Germany, Greece, China, and USA → several facilities involved

Snowmass 2021 – Letter of Interest Aug/31/2020

Polarized targets for laser-plasma applications

M. Büscher[1,2], A. Hützen[1,2], J. Böker[3], R.W. Engels[3], R. Gebel[3], A. Lehrach[3,4], P. Gibbon[5], A. Pukhov[6], R.W. Aßmann[7], T.P. Rakitzis[8,9], L. Ji[10,11], T. Schenkel[12], X. Wei[13]

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[13] Thomas Jefferson National Accelerator Facility, Newport News, VA 23606, USA

- Use a laser-generated electron beam for driving plasma wakefields in a second stage → HQ electron beam from ultra-compact setup
- See LOI and AF6 presentation by A. Irman
- Several facilities involved

Hybrid LWFA-PWFA staging (LPWFA) as a beam energy and brightness transformer

Arie Irman
Helmholtz-Zentrum Dresden – Rossendorf

Sebastien Corde[1], Andreas Döpp[2], Bernhard Hidding[3], Stefan Karsch[2], Alberto Martinez de la Ossa[5], Ulrich Schramm[6] - *for hybrid LWFA-PWFA collaboration*

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SnowMass2021- AF6 Oral Session 24 September 2010

MT ACCELERATOR RESEARCH & DEVELOPMENT

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Institute of Radiation Physics
Member of the Helmholtz Association
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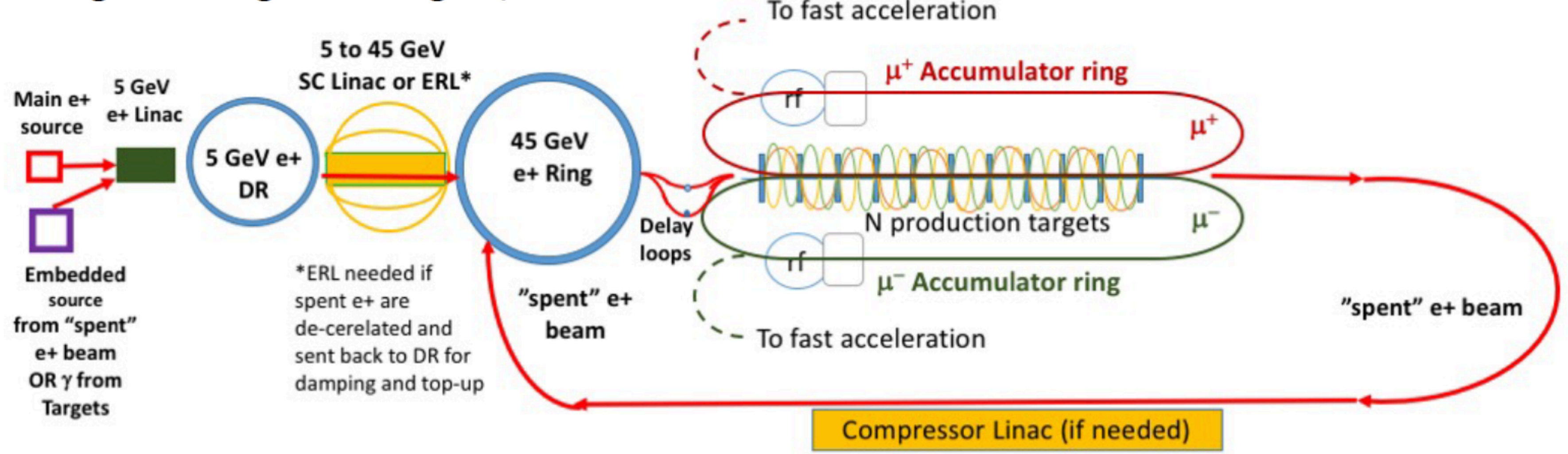
Thank you for your attention!

Backup slides afterwards

LEMMA source Accumulator ring – R&D

- Extraction of e^+ bunches to one or more muon production target-lines, produced $\mu^\pm$ are accumulated in two Accumulator Rings (AR), each $\mu^\pm$ bunch is "built" by several passages through the targets, to be then delivered to the fast acceleration chain



1. **TARGETS** Several options to be explored for the μ source
2. **BEAM PHYSICS** → design e^+ and $\mu^\pm$ rings with very high energy acceptance, design of Interaction Region and Separation Region for 3 beams (e^+, μ^+, μ^-)
3. **HIGH FIELD MAGNETS** → need to focus 45 GeV e^+ and 22.5 GeV $\mu^\pm$ together in a short low β-function IR → high gradient, large aperture and compact quadrupoles. Design multi-targets $\mu^\pm$ production line requires efficient 3-beams separation design, minimising particle losses, with high field, large aperture dipoles
4. **RF CAVITIES** → high gradient SCRF cavities able to cope with a high average train current (~100 mA)
5. **MUON COOLING** → longer $\mu^\pm$ lifetime at production allows moderate cooling mechanism to further reduce production emittance.
6. **MUON RECOMBINATION**